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ANALYSIS OF THE TRANSFER OF TRAINING, SUBSTITUTION AND FIDELITY OF SIMULATION OF TRAINING EQUIPMENT

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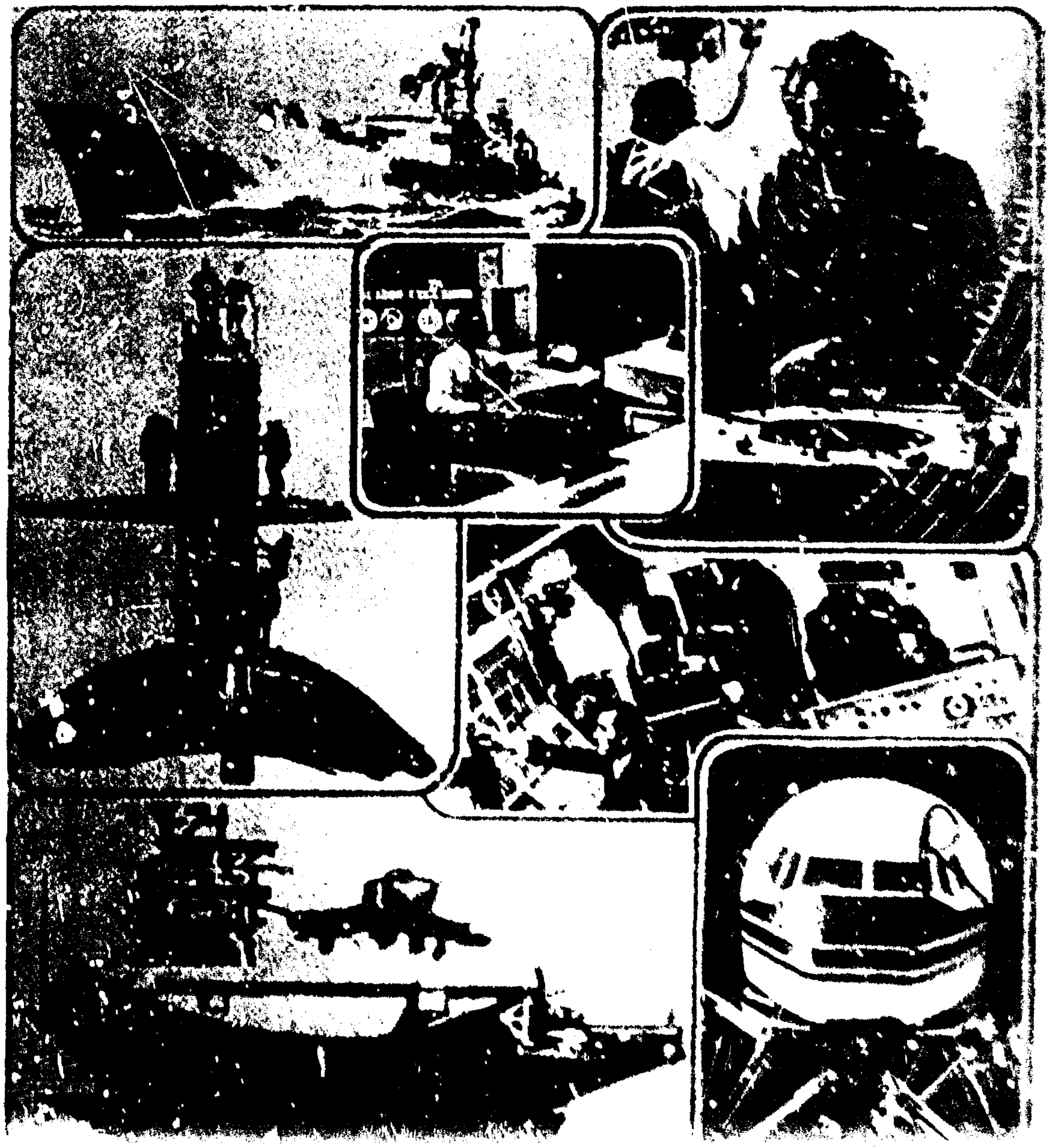

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NAVTRAEQUIPCEN TAEG Report 2

ANALYSIS OF THE TRANSFER OF TRAINING, SUBSTITUTION, AND FIDELITY OF SIMULATION OF TRAINING EQUIPMENT

1972

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ABSTRACT

ANALYSIS OF THE TRANSFER OF TRAINING, SUBSTITUTION, AND FIDELITY OF SIMULATION OF TRAINING EQUIPMENT

This report summarizes, evaluates and synthesizes the data on the training value of training devices. The report discusses the issues of substitution of some operational training time by training devices and the relationship between training effectiveness and cost (fidelity of simulation).

FOREWORD

This report was prepared as one element of a staff study on cost and training effectiveness undertaken by a Training Analysis and Evaluation Group (TAEG) team. It was prepared by Dr. Gene S. Micheli.

The main report prepared by the TAEG team, of which this report is a supplement, is entitled, "Staff Study on Cost and Training Effectiveness of Proposed Training Systems" (NAVTRAEQUIPCEN TAEG Report 1).

The report is separately published because it addresses an issue which has relevance not only for the Staff Study on Cost and Training Effectiveness of Proposed Training Systems (NAVTRAEQUIPCEN TAEG Report 1), but also for the broader questions of training equipment (device) fidelity of simulation and the substitution of training device-based training for training using operational equipments and environments.

ANALYSIS OF THE TRANSFER OF TRAINING, SUBSTITUTION, AND FIDELITY OF SIMULATION OF TRAINING EQUIPMENT

"If we could first know where we are, and whither we are drifting, we could better judge what to do and how to do it." - Abraham Lincoln

The purpose of this report is to analyze the current situation on the cost and training effectiveness of training devices.

The cost and training effectiveness of training devices are ideally determined by the collection of empirical data by controlled experiments. At present, however, there is a paucity of such data. What does exist will be summarized in terms of the commonality of findings. Specific current training situations will be analyzed to determine tasks which can be learned in the training system and in the operational situation.

From the results of the analyses of specific transfer/substitution studies, an attempt will be made to generalize to various types of training situations in order to arrive at an evaluation of the cost and training effectiveness of training devices.

"Cost effectiveness" will be used in this paper to mean the use of the least costly of several alternative training systems, all of which could equally produce men trained to a specified level of proficiency. Lower cost of training equipment allows (even demands) its use in place of operational equipment.

The "training effectiveness" of a training device is usually expressed as a measure of transfer of training. Transfer of training refers to the degree to which practice in a trainer carries over to (or affects) performance in an operational situation, as compared to the

performance of trainees who received no practice in the trainer. In other words, training effectiveness is the difference between a performance measurement on an operational task after practice on the training device and performance on the operational task without practice on the training device. (Trainees who receive practice in a training device are usually referred to as the experimental group; trainees who receive no practice in the trainer are referred to as the control group.)

Thus, transfer of training is the term used to describe how what is done (learned) in one situation affects what is done (performance) in another. Transfer of training is positive when a training situation aids subsequent performance. It is negative when it hinders that performance, and it is zero when training has no effect on later performance.

Most measures of training effectiveness are measures of transfer of training. Many different formulas exist for expressing the amount of transfer (References 1, 2, and 3).

Percent transfer based on improvement in performance on the operational task or on savings in time to reach a specified performance level on the operational task may be calculated from the following formula:

$$\%\ \text{transfer} = \frac{Zc - Ze}{Zc} \times 100$$

Where:

Zc = performance or time required on the operational (or transfer) task by the control group.

Ze = the corresponding value for the experimental group.

The Northrop Air Force Future Undergraduate Pilot Training System Study (Ref. 4) equated the percent transfer formula (based on savings in time) with "replacement percent" to denote that it is an index of the percent of time on the operational task which can be saved or "replaced" by time in the training device.

Roscoe of the University of Illinois Aviation Research Laboratory believed that the quantitative assessment of the transfer of training from training devices to operational tasks is not adequately described by the percent transfer measure. The fact that trainers result in a saving of time to reach a specified level of performance in the operational task is meaningful only if the time in the trainer is known. This resulted in the development of the transfer effectiveness ratio (TER) (Ref. 5). The TER is a measure for assessing the effectiveness of a training device by expressing the saving in time on the operational task as a function of the amount of time in the trainer. It is defined as time saved in the transfer (or operational) task, divided by the time required in the training device. The TER may be calculated from the following formula:

$$TER = \frac{Yc - Ye}{Xe}$$

Where:

Yc = time required by the control group to reach some criterion of proficiency in the operational (or transfer) task.

Ye = the corresponding value for the experimental group.

Xe = the training device hours received by the experimental group.

Examples of calculations of percent transfer and TER follow.

From data in Reference 6:

$$\% \text{ Transfer} = \frac{60 \text{ hrs.} - 6.5 \text{ hrs.}}{60 \text{ hrs.}} \times 100 = 89\%$$

$$\text{TER} = \frac{60 \text{ hrs.} - 6.5 \text{ hrs.}}{42.8 \text{ hrs.}} = 1.25$$

From data in Reference 7:

$$\% \text{ Transfer} = \frac{211 \text{ hrs.} - 18 \text{ hrs.}}{211 \text{ hrs.}} = 91\% \text{ (Flight check criterion)}$$

$$\text{TER} = \frac{211 \text{ hrs.} - 18 \text{ hrs.}}{213 \text{ hrs.}} = .91 \text{ (Flight check criterion)}$$

$$\% \text{ Transfer} = \frac{262 \text{ hrs.} - 113 \text{ hrs.}}{262 \text{ hrs.}} = 57\% \text{ (Criterion of completing B-Stage)}$$

$$\text{TER} = \frac{262 \text{ hrs.} - 113 \text{ hrs.}}{261 \text{ hrs.}} = .57 \text{ (Criterion of completing B-Stage)}$$

These data show that the same training device may exhibit different transfer effectiveness ratios depending upon the criterion of performance used. Also, for different stages of a curriculum, a training device may have different TER's. And, of course, the effectiveness of a training device depends greatly on how it is used. However, although the value of measures of effectiveness may change, they are useful for studying learning and transfer.

A number of transfer of training experiments have been performed which demonstrate that trainers can be used effectively to reduce operational (e.g., flight) training time by significant proportions. (See Appendix A for summaries of training system effectiveness studies.)

These transfer of training experiments lead to the following conclusions:

1. Simulators have cost and training value for pilot training, since they permit the learning of flight tasks in them. In fact, substantial amounts of simulator time can be used in place of flight time.

2. Most experimental work has been done on simple aircraft and trainers, but similar results have been obtained when complex aircraft and trainers have been used.

3. Different kinds of flight tasks have different transfer effects. Simulators are best for procedural and instrument flying tasks. Complex maneuvers have not been learned as well with the past state-of-the-art in simulation.

4. How a device is used may influence learning and transfer to a greater degree than trainer design.

Most of the studies were conducted during the 1940's and early 1950's. Similar research has recently resumed. The University of Illinois Aviation Research Laboratory found in 1971 (Ref. 5) that eleven hours of training in the old "Blue Box" (AN-T-18) resulted in a savings of nine hours of flight time (out of 46 hours) on the Piper Cherokee (transfer effectiveness ratio of 0.8). Eleven hours of training in the GAT-1 resulted in a savings of eleven hours of flight time (transfer effectiveness ratio of 1.0).

HumRRO, in 1971 (Ref. 6), conducted an evaluation of the Synthetic Flight Training System (SFTS), Device 2B24, using Army helicopter trainees who had just completed 110 hours of Primary training on the TH-55 and were ready to start instrument training (TH-13T). Compared to conventionally trained students who spent 60 hours in the aircraft, the SFTS trainees spent 42.8 hours in the trainer and 6.5 hours in the aircraft. A TER of 1.25 was calculated from the data available in the report. Also, calendar time was eight weeks, versus 12 weeks for the conventional program.

The NAVTRAEQUIPCEN conducted a transfer of training experiment in 1971 of Device 2F90, the TA-4J OFT (Ref. 7). The effectiveness of the device for training on the basic instrument portion of the advanced jet syllabus was evaluated by comparing groups given different training regimes. Three experimental groups were compared to each other and to a control group which had received the standard syllabus training. Of the three experimental groups, one received training only in flight, another group only in the trainer, and the third received only academic training on related principles of the basic instrument portion of the syllabus. All groups were given a flight check in the TA-4J aircraft after training. Following the flight check, students were recycled for as many flights (in the aircraft or in the trainer) as was estimated by the check pilot to be necessary to make them equivalent to those receiving the standard syllabus.

The results of the experiment are:

1. The flight check scores of the control, flight, trainer, and academic groups were 3.12, 3.03, 2.99, and 2.77, respectively. The control group was best; however, there was no statistically significant difference between the flight-trained and the trainer-trained groups.

2. Even after the students were recycled for as many sessions in the aircraft and in the trainer as the check pilots thought they required, the trainer group saved 4.7 flight hours (or three flights) compared to the control group. However, the trainer group required an additional 1.6 hours (or one session) on the trainer. This is a 55% savings in flight hours, which translates into a considerable savings in cost per trainer group student.

3. Calculations for transfer effectiveness ratios resulted in the values 0.91 and 0.57, depending upon the definition of criterion performance used. The TER's are interpreted to mean that for the portion of the syllabus experimented with, trainer sessions are almost equivalent to aircraft flights in training effectiveness, or have an equivalent value of 0.57 to 1, depending on whether is used the hours required to pass the flight check or the hours to complete the basic instrument stage (which includes recycled flights in the aircraft and trainer).

In an attempt to provide a common basis for comparing the results of different studies, percent transfer based on a savings in time (replacement percent according to Northrop) and TER's were computed by Northrop (Ref. 4). The tasks trained were contact flight procedures and maneuvers, landing, and takeoff. The percent transfer and Training Effectiveness Ratio for various studies are given in Table 1.

The preceding data convincingly demonstrate that flight simulator training transfers to aircraft and can be substituted for some flight time. This is true for civilian pilots of light aircraft, military undergraduate pilot training, and airline pilot transition training. Further evidence of the transfer and substitutability of flight training, of course, is NASA's Apollo Program in which 100% of the training for space flight and lunar landings was conducted in simulators.

Apparently it is not true, as is believed by some, that the airlines can conduct most (and eventually 100%) of its transition training in simulators only because their pilots are very experienced. The studies

TABLE 1. PERCENT TRANSFER AND TER'S CALCULATED FOR SEVERAL STUDIES
(After Reference 4)

TASKS TRAINED	AIRCRAFT	TRAINER	AUTHOR	% TRANSFER	TER
Procedures; Takeoff; Hover; Landing	Helicopter	Whirlymite	Caro, et al (1968) (Ref. 8)	9%	.17
Primary Flight Maneuvers	T-6 (SNJ)	T-6 Link	Flexman, et al (1954) (Ref. 9)	23%	.75
Landing	SNJ	SNJ Link	Payne, et al (1954) (Ref. 10)	61%	
Maneuvers	Light Aircraft	School Link	Flexman, et al (1950) (Ref. 11)	Approx 0	Approx 0
Primary Flight Maneuvers	SNJ	12BK1, SNJ Link, SNJ, Link C-3 Link	Mahler & Bennett (1949) (Ref. 12)	60% (12BK1) 71% (SNJ) 57% (C-3)	
Familiarization & Instruments Stages of Advanced	PBY4 (4-engine landplane) PBM (2-engine seaplane)	PBY4 Trainer, PBM Trainer, NA	Mahler & Bennett (1950) (Ref. 13)	PBY4 FAM: 18%, 19% 26%, 28% PBM FAM: 15%, 23% 25%, 30% PBY4 INST: 39%, 24%	
Flight Procedures & Maneuvers	B727 BAC 400	B727 simulator BAC 400 simulator	Houston (1970) (Ref. 14)	B727 (Motion): 30% B727 (Motion & visual): 61% BAC 400 (V&M): 63%	- .72 .67
Flight Procedures & Maneuvers	B707 B727	B707 simulator	TWA Training Dept (1969) (Ref. 15)	49%	.19
Flight Procedures & Maneuvers	DC-8	DC-8/1951 simulator	Meyer & Flexman (1967) (Ref. 16)	13%	.41

reported above provide sufficient evidence that flight training devices are also effective for neophyte pilot training.

Some discussion is warranted here about the experience of the airlines. They have followed a traditional pattern for many years. Each training program was modeled after earlier ones with very little change. Pilots practiced maneuvers in the airplane to develop skill needed for passing a rating check. Accidents occurring in training flights while practicing high risk maneuvers and particularly the prohibitive cost per flying hour has forced the airlines to use simulators for transition training.

The airlines have performed detailed task analyses as a basis for defining Specific Behavioral Objectives (SBO's) to restructure their training programs to make maximum use of simulators. For example, American Airlines has gone from 20.6 hours on its B727 aircraft in 1966, to 7.6 hours in 1969 (63% reduction of flight training hours). Check-rides by FAA Flight Standards Inspectors have demonstrated that pilots trained using a ratio of 28.2 flight hours to 7.6 simulator hours can qualify. American Airlines' goal is to achieve 100% training in simulators (due to cost). Its DC-10 transition training program is currently two hours of flight time.

In the military, also, training devices have been used as supplements to flight training. For the following reasons, however, there is little choice but to substitute for flight time by training devices (Ref. 16):

Cost: The complexities of current and future aircraft and weapon systems are driving the cost per flying hour to such a level that all

but "payload" or "mission" flight is prohibitively expensive. On this basis, alternatives to present concepts of flight training demand investigation, development, and implementation to provide adequately skilled aircrews.

Air Space: The speeds attainable by current and future aircraft require greater operating air space per unit than that known in the past. This fact, considered with the increasing demands for air service, places a premium upon an already overloaded air space. When saturation occurs, catastrophe may be the result. The implications for flying safety, as well as efficient operations, are readily apparent. Again, alternatives to present practices and procedures must be developed to better use and conserve this fixed resource of air space.

Flying Safety: Each flight in an aircraft is an exposure to danger, however small. Training flights, in addition, expose the trainee during the period he is least capable of coping with dangerous or emergency occurrences. The value of human life is, of course, incalculable as it has always been. The value per unit of current and future aircraft is such that the financial penalty for losing an aircraft, when alternatives can be made available, is too great to be justified.

Data such as presented above have apparently convinced Navy and Air Force planners that flight substitution is feasible. Consideration is being given to the substitution recommendations of the UPT studies. The Navy study (North American and Link, Ref. 17) of undergraduate pilot training states 45% substitution will be possible overall when a wide angle visual for operational flight trainers (OFT's) becomes available. The Air Force UPT studies state that 50% (Northrop, Ref. 4) and 47% (Lockheed, Ref. 18) will be possible.

The Navy UPT (North American/Link) recommendations for substitution of flight time by ground training devices were based on an analysis of the tasks involved in flight training. These tasks were analyzed to identify the kinds of learning processes involved, and to identify the kinds of demand they tend to make on the training setting. It was found, for example, that most instrument flight trainers are highly procedural, and require primarily that the training environment contain accurate representations of cockpit displays and controls. Other maneuvers, aerobatics for example, while containing significant procedural elements, also require pilot surveillance of a variety of out-of-the-window visual cues to position, attitude, heading, and airspeed. Because of the relative ease of simulating events represented in cockpit displays, motions and sounds, primary attention in allocating training tasks to simulation has been given to requirements for the representation of out-of-the-window visual information. Each of the non-instrument flight maneuvers trained in the undergraduate program requires out-of-the-window visual information. Some maneuvers require simple cues which are readily provided at reasonable expense. Others require more complex cues, at greater cost. A few require visual cues which have such extensive equipment implications that their incorporation in ground training devices would be uneconomical within the undergraduate program. In allocating flight tasks to ground trainers, consideration was given to the relative expense of ground and flight training, to assure the allocation of tasks to ground training which would, in fact, represent significant cost savings. Two hypothetical simulators, Simulator "A" and Simulator "B", were conceived in making tentative allocations.

Training devices using the Simulator "A" concept would have a three-degree-of-freedom motion system, and a visual system display CRT would have a 48° horizontal and a 28° vertical field of view. Cockpit controls and instruments would have the same extent of fidelity in current military and commercial flight simulators. Other features, such as task and maneuver demonstrations, performance measurement, feedback, and permanent recordings of performance, would be included. Training devices employing the Simulator "B" concept would have a 180° horizontal and 87° vertical field of view and will include a generalized earth (or sea), and sky with horizon. It will have a six-degree-of-freedom motion system. Other characteristics will be similar to those described in the "A" concept.

A set of ground rules was developed by North American and Link to guide the estimation of the relative effectiveness of various allocations of flight tasks to ground training devices. The extent of substitution of training device time for flight time resulted from the application of these ground rules. In defining ground rules for the reduction of flight hours through the use of ground simulation, the recent training literature was reviewed for empirical evidence of successful substitutions of device for aircraft time. Also, analyses were made of the maneuvers to be trained in the recommended program and of the simulator capabilities available for supporting this training, to define the pilot task elements to which ground training is applicable. Device design concepts were developed to incorporate these task element-related capabilities based on the identification of task elements within the capabilities of device concepts. An analysis of flight tasks likely to be employed

in training naval pilots in the future program identified the kinds of learning functions involved in each task. This analysis was used to anticipate the types of training setting most appropriate to these functions, and estimates were made of the extent to which each task depends on each function. Guidelines were developed for assigning percentages of flight tasks to training devices:

a. Substitution of simulator for aircraft flight time is determined primarily by the proportion of maneuver, or task training time, which would be devoted in flight to learning procedural or fixed-sequential task elements. Each task involved in aircraft and system operation contains a significant procedural component. That is, each task requires the selection, initiation and execution of some fixed sequence of control outputs whose magnitude and timing are keyed to sets of relatively well-defined events. Ground simulation is particularly effective in training these procedural task elements because, by definition, they involve cues to control actions which can be readily identified and, in most cases, adequately represented in simulation.

b. Approximately 25% of the time normally spent in solo flight can be re-allocated to ground simulation.

c. Approximately 75% of instrument and radio instrument flight training, which does not involve an out-of-the-window reference, can be provided in ground simulation devices. The motion cue requirements in almost all of the procedural and skill elements of instrument flight are well within the state-of-the-art, and only minimal visual requirements exist in this training stage. Near-perfect fidelity of instrument display and control representation is readily available, making ground

simulation almost totally equivalent to actual instrument flight. The primary discrepancy is in the stress involved in actual aircraft flight, and the knowledge that inaccurate performance can have serious consequences. For this reason, it is essential that skills learned in the unstressed ground trainer environment be demonstrated in actual flight.

d. Approximately 50% of dual flight time, not involving motion and visual capabilities outside the simulation state-of-the-art, can be provided in ground simulation. The superior capability of the simulator for permitting instructor monitoring of student performance, the capability for practicing maneuvers and procedures which could not be practiced in the air, and the simulator capability for concentrating only on training-relevant task elements contribute significantly to its ability to substitute for dual instruction time.

An example of recommendations made for substitution of simulator time that may be made for flight time in the Advanced Jet syllabus is shown in Table 2, which is taken from a draft of Ref. 17, dated April 1971.

If the Navy and Air Force future UPT studies' analyses and conclusions that as much as 50% (and 75% in some specific areas) of flight time can be substituted for by simulators seem high, consider the viewpoints of participants in a symposium on pilot training and the pilot career conducted by the Rand Corporation (Ref. 19).

In discussing the question, "How far do all present want to go with ground-based simulation in substitution for aircraft?", a representative of the University of Illinois Institute of Aviation proposed aiming for 100%. He projected an answer for the commercial airlines, which would be

Table 2. FLIGHT SIMULATOR SUBSTITUTION, CURRENT SYSTEM
ADVANCED JET, TA-4

STAGE	SYLLABUS HOURS	SIM A SUB HRS	SIM A SUB %	SIM B SUB HRS	SIM B SUB %
Familiarization	11.2	2.8	25	5.6	50
Basic Insts.	8.4	5.6	67	5.6	67
Inst. Nav.	36.1	29.6	82	29.6	82
Formation	12.6	0.0	0	2.8	22
Night Flying	8.5	1.5	18	5.6	67
Oper Nav	9.3	0.0	0	4.0	43
Appl. Nav	4.5	3.0	66	3.0	66
Air/Grnd Wpns	12.1	0.0	0	5.5	45
Tactics	9.9	0.0	0	4.4	44
Air/Air Wpns	4.0	0.0	0	1.0	25
Car Qual	12.4	1.6	13	4.8	39
	129.0	44.1	34%	71.9	56%

to take pilots straight from the simulator to flying the aircraft. A commercial airlines representative confirmed that for the reason of cost, the airlines' objective is to perform 100% training in simulators.

A representative of the USAF Human Resources Laboratory stated that a 100% goal is a meaningful and viable goal provided that constraints operating to prevent its achievement are recognized. Such constraints are: cost, probability of not achieving 100% fidelity, stress, motivation, and joy of flying. In his opinion, the 100% goal is not an unreasonable aspiration under such conditions.

Most of the work was done with pilots, probably because of the desire for information in such a high risk activity. Another reason may be that the feasibility of substitution is readily apparent. Even with the paucity of transfer data in other areas, however, there is convincing justification for use of training device substitution. Further, substitution could be started prior to the collection of empirical evidence in many cases because of the relatively small risk involved.

Studies of non-flying activities in which transfer data was obtained follow. Device 3A105, Tracked Vehicle Driving Trainer (M48A3 tank), was evaluated at the Tracked Vehicle School, Camp Pendleton (Ref. 20). It was found that driver training using the trainer was as effective as training on the actual tank. Training was accomplished in approximately an equal amount of time using the trainer versus using the actual tank. Since the time differences between those groups using the trainer and those using the tank alone are almost equal, it was concluded that there was a one-to-one replacement ratio between the trainer and the tank itself as far as driver training is concerned. Further, since there is

a significant cost differential between the two modes of training, the training device represents a more cost-effective method of training tank drivers.

An evaluation of the Carrier Air Traffic Control Center portion of a large Tactical Advanced Combat Direction and Electronic Warfare System was conducted at the Fleet Anti-Air Warfare Training Center, Point Loma. Transfer data were collected on the USS Constellation and USS Midway (Ref. 21). The data indicate that increasing the time spent in the trainer results in increased performance at sea. The findings also show that team, sub-team, and individual capabilities to deal with recovery contingencies and emergencies improve.

Device 2F69B, P-3A Aircraft Weapon System Trainer, at Patuxent River, was evaluated using training squadron ASW crews (Ref. 22). Data collected in the trainer indicated an increase in performance throughout five Weapon System Trainer (WST) sessions. This increase occurred despite the fact that instructor aid was systematically decreased while at the same time the level of task difficulty was increased. The improvement in task performance was reflected in measures of accuracy and efficiency. The accuracy of completing such mission tasks as navigational stabilization, search, localization, and attack consistently improved during the trainer sessions. Improved accuracy was accompanied by improved efficiency. As the students progressed through WST training, they reduced the time spent in completing each evolution.

To demonstrate the extent to which training is transferred to the airborne environment, a second phase of the study was directed at obtaining performance measures in the operational setting. Attempts

to obtain submarine services were unsuccessful; therefore, the transfer data portion of the study was conducted using surface ships as targets. The analysis of the data for this phase of the study has not been completed as of this writing.

In support of transfer data showing the value of training devices, is the analysis of training situations to determine tasks that can and cannot be trained in the training device and in the operational situation. An example of such an analysis will be given for Device 14A2, Surface ASW Attack Trainer, for which a study of the retention of skills learned on it was performed, but for which no transfer of training data are available. In the skill retention study (Ref. 23), performance changes by members of ASROC teams undergoing training at Norfolk were measured, and their skills reevaluated at periods ranging from eight to sixteen weeks after training. Two rather straightforward conclusions were reached. One is that the trainees do, in fact, learn in the trainer. The other is that they rapidly forget what they have learned when they go to sea. It was concluded that shorebased team training should be made a regular part of the operating schedule of ASROC-equipped ships. The consensus expressed was that Device X14A2 practice was as good or better than at-sea practice, since it allows for multi-unit problems and unexpected contingencies.

TAEG team members analyzed the tasks that can be performed on Device 14A2 and in the operational situation. They concluded that if Device 14E19, Basic Operator/Team Trainer for the AN/SQS-26CX Sonar, is used in conjunction with Device 14A2, everything that could be trained at sea could be conducted in the trainer. In fact, at sea it

is extremely difficult to conduct other than basic training problems, and intermediate and advanced level exercises are virtually never conducted. Intermediate and advanced exercises are not conducted in the trainer either, but such is not only feasible, but highly desirable. This analysis could apply in general to various attack trainers. Whether this analysis is correct will be tested soon with the planned training effectiveness evaluation of Device 14A2 which will obtain transfer measurements.

A recent study conducted by HumRRO (Caro, 1970, Ref. 24) provides some support that transfer can be predicted. An approach called Equipment-Device Task Commonality Analysis was developed. It identifies the stimuli and responses involved in the operational situation and the training device, and then determines the extent to which the stimuli are common to both the operational equipment and the device. It then looks at response commonality, that is, the extent to which responses made in the operational environment may be made in the training device. A prediction of positive or negative transfer of training from the device to the operational equipment is made from the information concerning stimulus and response commonality, and using the following "principles" of transfer of training as guidelines: (1) Positive transfer will occur when both stimuli and responses are similar in the training situation and the operational situation, and (2) Negative transfer will occur when the stimuli are similar in the training and operational situations, but the responses to the similar stimuli are different. This procedure was applied to a training device (Link 1-CA-1, a fixed wing basic instrument trainer modified to a helicopter configuration) whose transfer of training value had been previously determined empirically. It was concluded that

relatively little task commonality exists between it and the operational equipment (TH-13T helicopter). Predominately negative transfer was "predicted" from its use, a "prediction" that was supported by the earlier transfer of training study. (It is unfortunate that "prediction" was not done prior to the transfer study.)

The relationship between training effectiveness and cost has been discussed by many authors since 1954, when Miller (Ref. 25) introduced his now well-known hypothetical relationships among degree of fidelity of simulation, transfer of training, and simulator cost. His curves depicted an increase in both transfer of training and cost with increasing degree of fidelity of simulation. The objective is to find the optimum point of interaction between fidelity, transfer and cost, or in other words, to obtain the highest degree of transfer for the lowest possible cost. The implication is that it is necessary to make compromises between economic and training goals when selecting training media.

The problem with Miller's relationship is not so much the hypothetical shapes of the curves, but the implicit assumption that training value increases as a function of fidelity of simulation. Undoubtedly, increasing fidelity of (engineering) simulation results in increased cost. However, Miller's curve which shows an increasing amount of transfer with increasing fidelity of simulation is disputable.

A recent study (Erickson, et al, 1972, Ref. 37) stated, "Only a handful of studies have been concerned with the relationship between fidelity of simulation and training value. Conflicting results have been obtained: in some studies high fidelity simulation produced

better training, while in others, a lesser degree of fidelity produced equally good training. No studies have been reported in which higher fidelity is associated with poorer training." The authors then go on to recommend high-fidelity simulation.

But even if low fidelity simulation resulted only in training effectiveness equal to that obtained from high fidelity trainers, the obvious cost effectiveness requires consideration of low fidelity of simulation for appropriate tasks. Many of the studies demonstrating that low fidelity training devices are as effective as high fidelity devices or operational equipment have been concerned with procedural tasks in which every motion must be performed in sequential order (e.g., Grimsley, 1969, Ref. 26; Prophet and Boyd, 1970, Ref. 27). Several studies were done using flight simulators differing in their degree of fidelity of simulation (Mahler & Bennett, 1949, Ref. 13; Wilcoxon, et al, 1954, Ref. 28; Dougherty, et al, 1957, Ref. 29), and one study with five different degrees of fidelity in submarine control (Newton, 1959, Ref. 30). (The latter study, however, measured transfer not in an operational situation but to the simulator having the highest degree of fidelity.) Generally, despite differing degrees of fidelity, there was no difference in transfer effect between trainers. It is contended by the present report that training effectiveness is more a function of the manner in which the trainer is used than of the fidelity of the trainer.

The goal to approach complete duplication of operational equipment should not be attempted unless a training situation analysis reveals its necessity. It is costly to do so, and in many instances, is

unnecessary for effective training. The critical element of training is transfer to operational performance of the skills, knowledges, and attitudes developed in the training situation. This depends very heavily on how the training device is used rather than on how realistically the device is designed.

Maximizing fidelity is a very costly endeavor. By minimizing fidelity, effective training can be provided with a considerable reduction in cost, thus resulting in the savings of resources that could then be used elsewhere.

CONCLUSIONS

In 1954, Gagné (Ref. 31) stated that there are "a number of studies on the 'effectiveness' of training devices which are generally characterized by sound but unstartling conclusions." The findings of studies since that time are quite similar, so again his statement could be made. But, the view held here represents a different interpretation of the findings, namely, that trainees can learn some things about flying (or other operational tasks) while they are practicing in training devices. Though the research results themselves are not necessarily "startling", what is startling is the resistance to substitution of some operational training time by training devices. It was not until costs of non-revenue training flights for the commercial airlines became so tremendous that simulators became considered anything but "supplements" to flight training. As a result of this demonstration by the airlines of the feasibility and practicality of substitution of flight time by practice in training devices, the military should boldly adopt the

policy of substitution for the appropriate portions of the flight training and other operational training syllabi.

Training effectiveness evaluations of training systems have demonstrated that learning, retention and transfer occur in situations where "exact simulation" is not present. (These examples do not necessarily violate the theory of "identical elements," which is an approach of analyzing transfer in terms of specific elements common to tasks. All transfer effects cannot be related to an analysis of specific stimulus-response relationships (Ref. 32).) We may generalize from the examples of training effectiveness evaluations that training effectiveness results not from attempting to approach identity of task elements, but from using a training device in a manner that permits trainees to practice the behaviors critical for performance in the operational situation.

APPENDIX A

SUMMARY OF TRAINING SYSTEMS

EFFECTIVENESS EVALUATIONS*

* Mr. Joseph A. Puig of the Human Factors Laboratory prepared most of this Summary.

SUMMARY OF TRAINING SYSTEMS EFFECTIVENESS EVALUATIONS

Early History:

	Vehicle	Simulator	Skills Taught	Experiment	Results
1939, (Ref. 12)	Civilian light aircraft	Link AN-T-18	Basic contact flight for civilian pilot training program.	Analysis of performance records (N=10). No control group.	Estimate that 5 to 7 hrs. in trainer was equivalent to 3 hrs. in A/C. Savings of 2 to 4 hrs. air time. (Inconclusive)
1940, (Ref. 12) (NRC, Wash., D.C.)	Civilian light A/C	Link AN-T-18	Basic contact flight for civilian pilot training program.	Analysis of performance records (N=10). No control group.	Estimated 2-1/2 hrs. saving in air time with 6 hrs. of trainer time. (Inconclusive)
1941, (Ref. 12) (NRC, Wash., D.C.)	Civilian light A/C	Link AN-T-18	Basic contact flight for civilian pilot training program.	Instructor performance ratings. Three groups of 14, 8, and 11 civilian pilot training students.	Groups with more Link trainer time were rated higher than group with only one hour of training. (Inconclusive)
1942, (Ref. 12) Naval Reserve Aviation Base, Long Beach, Calif. (Later transferred to Los Alamitos base)	Military	Link	Basic flight training.	(N=146) No control group.	(1) Reduced number of dual instruction hrs. for solo. (2) Reduced number of students receiving downs on their check flights. (Inconclusive)
1943, (Ref. 12) Naval Flight Preparatory School, William Jewell College, Liberty, Missouri	Military	Contact Link	Basic flight training.	(N=1400) 1/2 received 10 one hr. sessions on Contact Link Trainer. Other 1/2 no synthetic training.	Experimental students tended to slight advantage over control students in capability for solo time, actual solo time, and instructor's grades. (Differences were not statistically significant.)
1945, (Ref. 12) Naval Air Station, Memphis	Military	12BK-1 Primary Landing Trainer	Primary training	(N=166) 1/2 experimental and 1/2 control.	(1) Experimental students completed syllabus faster than controls by 16%. (2) Control group had 10% more flight failures in A stage, 5% more in B stage. (3) Differences disappear by end of C stage.

Early History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1949, (Ref. 12) 151-1-18 (Univ. of Illinois)	SNJ	(1) 12-BK-1 Landing Trainer (2) C-3 Cyclo-ramic Link Trainer (3) SNJ Cyclo-ramic (General) Link (1-CA-2)	Instrument training and control skills	(1) experienced S's (solo flight time) (N=234) (2) 10 hrs. syn. trainer (N=465) (3) control group (N=427)	Three trainers equivalent: accidents reduced 40%; failure rate down 33%.
1949, (Ref. 33) 71-16-5 (Univ of Ill. and Link Av.)	SNJ-5 Modified for civilian use.	SNJ Cycloramic Link (1-CA-2)	Basic contact flight training.	(2 groups of 6 college students ea. 12 hr. flt. syllabus.) Trainer group: 8 hours on trainer. Control group: 11 hrs. A/C.	12 hrs. to learn in air; 5 hrs. air time for trainer group. Fewer errors for trainer group.
1950, (Ref. 13) 999-1-1 (Psychol. Corp.)	PBM (2-engine seaplane) PB4Y (4-engine land plane)	PBM-OFT PB4Y-OFT	Familiar and instrument training.	Series of controlled experiments using 23 matched prs. of students for each trainer.	Flight time reduced 1 1/2 hrs. out of 12 hr. syllabus for INST; no saving for FAM stage. Fewer errors in both stages.
1946, (Ref. 34) St. U. of Iowa 57-1-1	Floating reticle sight	3-A-2 3-A-35 Aerial Gunnery Trainers	Leading an aircraft target.	5 groups of N=20 each. Grp 1: Standard 3A35 (track and lead visible correct point of aim) Grp 2: Only tracking point of aim; then tracking and leading Grp 3: Standard 3A3 (small target movement) Grp 4: 3A2; then 3A5 Grp 5: 3A35 "on target" lights (correct point of aim not visible) Transfer test: 3A35 with no visible correct point of aim.	(a) No differences among training methods. (b) Trainees improve with practice (c) Ceiling reached early; data suggest further training (esp. "on target" lights might raise final level.)

Early History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1946, (Refs. 35, 36, 37) Tufts College 58-1-1 58-1-2 58-1-4	Anti-Aircraft Mk 18 Gunsight	3-A-40 MK 18 Coordination Trainer	Simultaneous tracking and ranging	Exp. 1 (N=3 each): Exp. grp. given cues in earphones for "under" or "over' range on alternate trials for 20 trials; dropped for next 12 trials.	Both groups asymptote at 12th trial. Supplementary cue (augmented feedback) aids ranging performance but not learning.
				Exp. 2(N=5 each): Same as Exp. 1 except grps matched, based on 1st trial scores.	Earphone group obtained slightly bigger advantage--till earphones removed.
				Exp. 3(N=5 each): Exp. Grp. trained on 5 different target cycles, Control Grp on one target cycle (path).	1 target cycle group performed better (due to familiarity with path).
				Exp. 4(N=5 each): Grp 1: Practice on 1 target cycle (25 trials). Grp 2: Practice on 5 target cycles (25 trials). Grp 3: Little practice (2 trials) Transfer test: unfamiliar target cycles.	Transfer scores (2 trials) for Grps 1 and 2 nearly as high as for learned courses. Grp 3 scores like 1st and 2nd trials of learning. (High degree of transfer demonstrated).

Early History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1947, (Ref. 38) St. U. of Iowa 57-1-5	Floating reticle sight	3-A-2 Aerial Gunnery Trainer	Leading an aircraft target.	Exp. 1: (N=12) 32 trials a day (22 min.) for 17 days. (4 identical blocks of 8 attacks.) 1st 3 blocks each day was practice (correct point of aim visible). For 4th block correct point of aim not visible. 18th day used different (more difficult) attacks (transfer test).	Learning: Performance much better when point of aim visible, and learning curve steep till 6th session. Test trials learning curve has gradual increase then spurts at 14th trial. Transfer: Considerable (50% of scores of familiar, easier attacks).
1947, (Ref. 39) Tufts College 58-1-5	Anti-Aircraft MK 18 Gunsight	3-E-7 Ranging, Tracking Aiming Point Assessor	Simultaneous tracking and ranging.	(N=3) For each of 10 days received 60 trials (consisting of 4 different pursuit attacks).	Meter scores were unreliable, but graphic records showed rapid improvement on early trials for azimuth, elevation and range. In other respects the curves differed. For azimuth no S improved after trial 18. In elevation there was improvement till trial 48. In ranging, there was great variability for all S's.

Summary of above aerial gunnery studies: The studies resulted in ways to modify the devices and the recommendations for improving training. However, the primary concern of the E's was to obtain basic data on the learning of tracking skills. The evaluations of the training devices, per se, were in the nature of a secondary fallout. That is, for the transfer experiments, no attempt was made to obtain transfer measures in an operational situation. Instead, transfer consisted of test trials on the trainer with unfamiliar target speeds and courses.

Early History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1953, (Ref. 40) Dunlap & Associates 1043-00-2	Anti-Aircraft MK 18 Gunsight	3-A-40b	Simultaneous tracking and ranging.	Grp 1 (10 aircrewmen): 3-A-40b Grp 2 (10 aircrewmen): Standard squadron in the air. Grp 3 (10 aircrewmen): No aerial gunnery training Transfer test: Fire guns from P2V bomber at an attacking F9F aircraft. (Camera rather than bullets used to record performance.)	(a) No differences in tracking scores. (b) Tendency for air-trained and untrained groups to range better. (c) Trainer - trained and air-trained groups equivalent and superior to untrained group on simultaneous tracking and ranging ("success score").
1950, (Ref. 41) Univ. of Illinois 71-16-7	SNJ	School Link with "blackboard" runway.	Ground reference maneuvers (landings, forced landings, pylon 8's)	N=20 college students 10 on trainer 10 principles training	Trainer group = 2.59 errors Control group = 4.27 errors
1954, (Ref. 28) (Psychol. Corp.) 999-2-1 NAS Pensacola	SNJ	SNJ OFT (Specialized, high fidelity)* and NavBIT (General low fidelity)**	Instr. training including radio range.	Progress-at-own-rate syllabus and ground training under a blocked sequence Std. Blk Syl NavBit N=96 OFT N=33 Exp. Block Syl N=168 N=52	(1) saved an av. of 1.3 hrs. in flight or $>$3000 hrs/yr or, 1 flight out of 11 bas. inst. flts. (2) NavBIT equal in effectiveness to SNJ OFT for basic instrument training and slightly superior for radio range work.

*NavBIT: The standard Navy synthetic trainer for basic instrument and radio range practice. Greater stability than SNJ OFT; "crab" which tracks record of flight path; additional headsets;

**SNJ OFT: A high fidelity electronic trainer which simulates the SNJ aircraft. Accurately simulates A/C characteristics (e.g, motion and sounds).

Early History, (Cont'd)	Vehicle	Simulator	Skills Taught	Experiment	Results
1954, (Ref. 9) (A.F.) Lackland AFB	T-6 (Navy SNJ)	P-1 (1-CA-2 SNJ Cycloramic Link)	Procedures; maneuvering	95 aviation cadets; 47 in trainer. Substituted 40 simul. hrs. for 30 flt. hrs. in a 130 hr. syllabus	40 sim. hrs. + 30 flt. hrs. ratio = 0.75
1954, (Ref. 10) 71-16-11	SNJ	Cycloramic Link	Approach and Landing	Experimental group (N=6) vs. control group (N=6).	61% fewer trials & 74% fewer errors for simulator group.
1957, (Ref. 29) 71-16-16	SNJ	Cycloramic Link, photo-mockup, procedures trainer.	Procedures	3 trainer groups compared to each other and flight group.	All groups equal after three air trials.

Recent History:	Vehicle	Simulator	Skills Taught	Experiment	Results
1968, (Ref. 42) (HumRRO)	Army Helicopter	1-CA-1 modified to rotary-wing configuration.	Instrument flight in rotary wing training. (U.S. Army Aviation School)	Total N=145. 3 groups: 0 hrs., 10 hr., and 20 hr. synthetic training. All groups received 25 hrs. flight training.	No significant difference between groups.
1968, (Ref. 8) (HumRRO)	Army Helicopter	"Whirlymite" captive helicopter	Rotary wing contact flight.	Total N=132. Divided into 2 experimental groups and 2 control groups with no training on device. 0, 3 1/4, 7 1/4 hrs. of practice.	(1) 10% attrition for flying deficiencies in exper. groups. 30% attrition for control groups. (2) Two hrs. less flight training needed to solo for exper. groups. (3) Flight grades higher early in training.

Recent History (Cont'd)

<table>
<tr><th></th><th>Vehicle</th><th>Simulator</th><th>Skills Taught</th><th>Experiment</th><th>Results</th></tr>
<tr><td>1966, (Ref. 43)
Dunlap</td><td>Automobile</td><td>Aetna Drivo-trainer</td><td>Automobile driving</td><td>Comparison of untrained group (N=88) with group trained on simulator. (N=88)</td><td>Better test-driving performance with experimental (trainer) group than with control group.</td></tr>
<tr><td>1966, (Ref. 43)
Dunlap</td><td></td><td>Device 1BZ2 Maneuvering Tactics Trainer</td><td>Surface Ship tactics.</td><td>1BZ2 Exercise Series containing 14 problems were used for measurement.</td><td>Criterion-referenced meas. sys. developed which could be applied to a transfer study with Device 20A61.</td></tr>
<tr><td>1971, (Ref. 44)
(NTDC)
Naval Air Tech. Ctr., Glynco)</td><td>Airborne ECM Systems</td><td>15E18 Tactical ECM Trainer</td><td>Operators are trained to locate and classify emitters, and to select proper countermeasures.</td><td>Learning measured through performance improvement.</td><td>(1) Trainees rapidly reached required performance levels due to prior operational equipment experience.
(2) Not utilized to full capability. Recommended more effective use.</td></tr>
<tr><td>1971, (Ref. 5)
Univ. of Illinois</td><td>Piper Cherokee</td><td>(1) AN-T-18 (Link "Blue Box")
(2) GAT-1</td><td>Flight course leading to private pilot certificate.</td><td>52 students into four groups: (A) previous flt. trng; (B) A/C; (C) AN-T-18; and (D) GAT-1.</td><td><table>
<tr><th>Grp.</th><th>Av. Flt. Hrs. to Crit.</th><th>Tnr Hrs.</th><th>Sav. Flt. Hrs.</th><th>Trans. Effec. Ratio</th></tr>
<tr><td>A/C</td><td>45.5</td><td></td><td></td><td></td></tr>
<tr><td>AN-T-18</td><td>36.5</td><td>11.0</td><td>9.0</td><td>0.8</td></tr>
<tr><td>GAT-1</td><td>34.5</td><td>11.0</td><td>11.0</td><td>1.0</td></tr>
</table></td></tr>
<tr><td>1969, (Ref. 23)
Honeywell</td><td>ASROC-equipped ships</td><td>X14A2 Surface Ship ASW Attack Trainer</td><td>ASW Team Trainer</td><td>Three Conditions:
A-No refresher training (N=5)
B-Full team refresher training (N=6)
C-Key part team refresher trng (N=6)</td><td>Skills learned in ASROC trainer lost within 16 weeks at sea but regained quickly with refresher training.</td></tr>
</table>

Recent History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1971. (Ref. 45) Bunker-Ramo	S-2E aircraft (4-place, twin engine, carrier-based ASW aircraft)	2F66A WST	Weapons system training. Both team and individual trng for air anti-submarine warfare missions.	To demonstrate learning through measured performance improvement. Subjects: VS-41, San Diego N=13, VS-30, Key West, N=12. (Same subjects performed in different operator positions on different sessions.)	(1) #4 Oper. (Julie-Jezebel) showed substantial learning. #3 (MAD, ECM, radar and Nav. Computer) and TACCO showed minor improvement. (2) San Diego students gained more than Key West students (Difference resulting from location). (3) More frequently used as individual than team trainer. (When first used as team trainer, performance decreases, then improves.) (4) Instructor evaluations of trainer (via questionnaire) - criticism of equipment. Reliability and lack of realism of A/C simulation inputs. San Diego instructors rated device highly; Key West instructors did not.

Recent History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1970, (Ref. 46) Bunker-Ramo	613 Flasher Class Submarine	21B20A Advanced Submerged Control Trainer	Submarine Control under normal and emergency conditions.	Compared performance of 16 student crews and five experienced crews on 21B20A (SSN 613 class), and a trainer for SBN 627 class submarine.	Student performance 90% of experienced crew performance for tasks of attaining ordered depth & maintaining depth during speed changes; student performance 40% of experienced crews for task of regaining ordered depth during diving buoyancy. SSN 613 & SSBN 627 trainers result in training improvement. Negative transfer of SSN 594 trainer when substituted for 21B20A during repairs. No negative influences observed as consequence of alternating sessions on SSN 613 and SSBN 627 trainers.
1971, (Ref. 20) Bunker-Ramo	M48A3 Tank	3A105 Tracked Vehicle Driving Trainer.	Drive the M48A3 tank.	One group trained on tank and tested on tank; another group trained on trainer and tested on tank.	100% transfer from trainer to tank, in equal amount of time.
1971-72 (Ref. 21) Bunker-Ramo	Carrier Air Traffic Control Center	Carrier Air Traffic Control Center Trainer.	Carrier Control of aircraft.	Trained with different amount of time in the trainer; then tested at sea.	Increasing the time spent in the trainer resulted in increased performance at sea.

Recent History (Cont'd)

	Vehicle	Simulator	Skills Taught	Experiment	Results
1971-72 (Ref. 22)	P-3A aircrew	2F69B (P-3A Weapon System Trainer)	Air ASW Tactics	Practice in trainer; then transfer to flight.	Improved on the trainer; in-flight transfer data analysis not yet completed.
1971-72 (Ref. 7)	TA-4J	2F90 (TA-4J Operational Flight Trainer)	Basic Instruments	Groups: (1) Control (standard training) (2) Flight only (3) Trainer only (4) Academic only	No difference on flight check between flight and trainer groups. Savings in flight hours of 55%.

SOME GENERAL CONCLUSIONS

- Experiments reveal that substantial amounts of air time can be substituted for by simulator time.

- Most experimental work has been done on simple aircraft and trainers.

- Different kinds of flight tasks have different transfer effects.

- The level of simulation and kind of trainer importantly influence transfer.

- Careful specification of both trainer and operational tasks is necessary if transfer is to occur.

- Motion of particular kinds affects trainee performance and transfer.

- Adding motion and visual displays increases fidelity requirements. Coupling of these is a major issue.

- How a device is used may influence learning and transfer to a greater degree than trainer design.

- Differences between training and operational equipment are necessary to exploit training technology.

- A precise specification of tasks and measures of operational transfer tasks is vital to effectiveness evaluation.

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